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Data and Computer

Communications

7th Edition

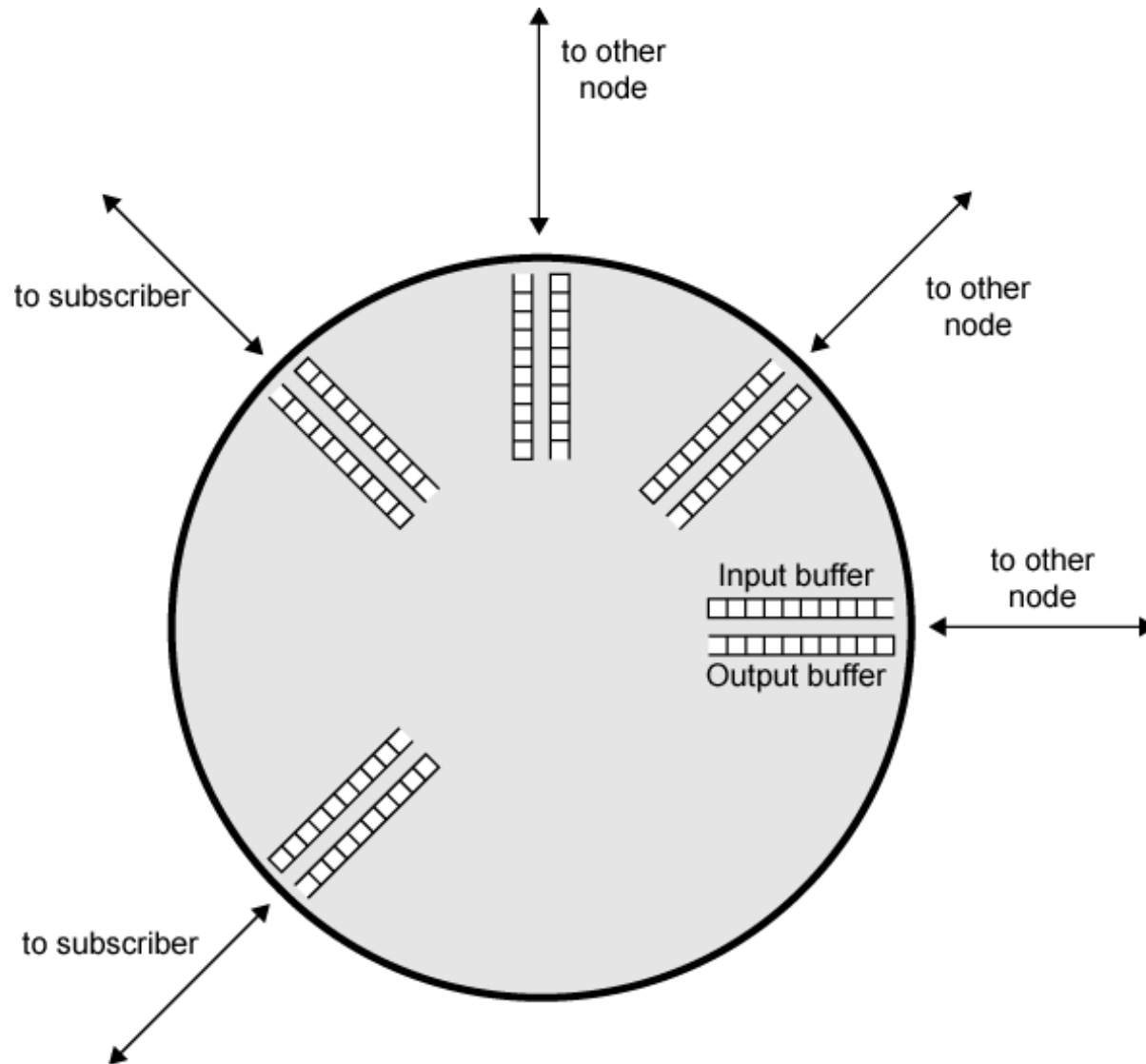
Chapter 13

Congestion in Data Networks

What Is Congestion?

- Congestion occurs when the number of packets being transmitted through the network approaches the packet handling capacity of the network
- Congestion control aims to keep number of packets below level at which performance falls off dramatically
- Data network is a network of queues
- Generally 80% utilization is critical
- Finite queues mean data may be lost

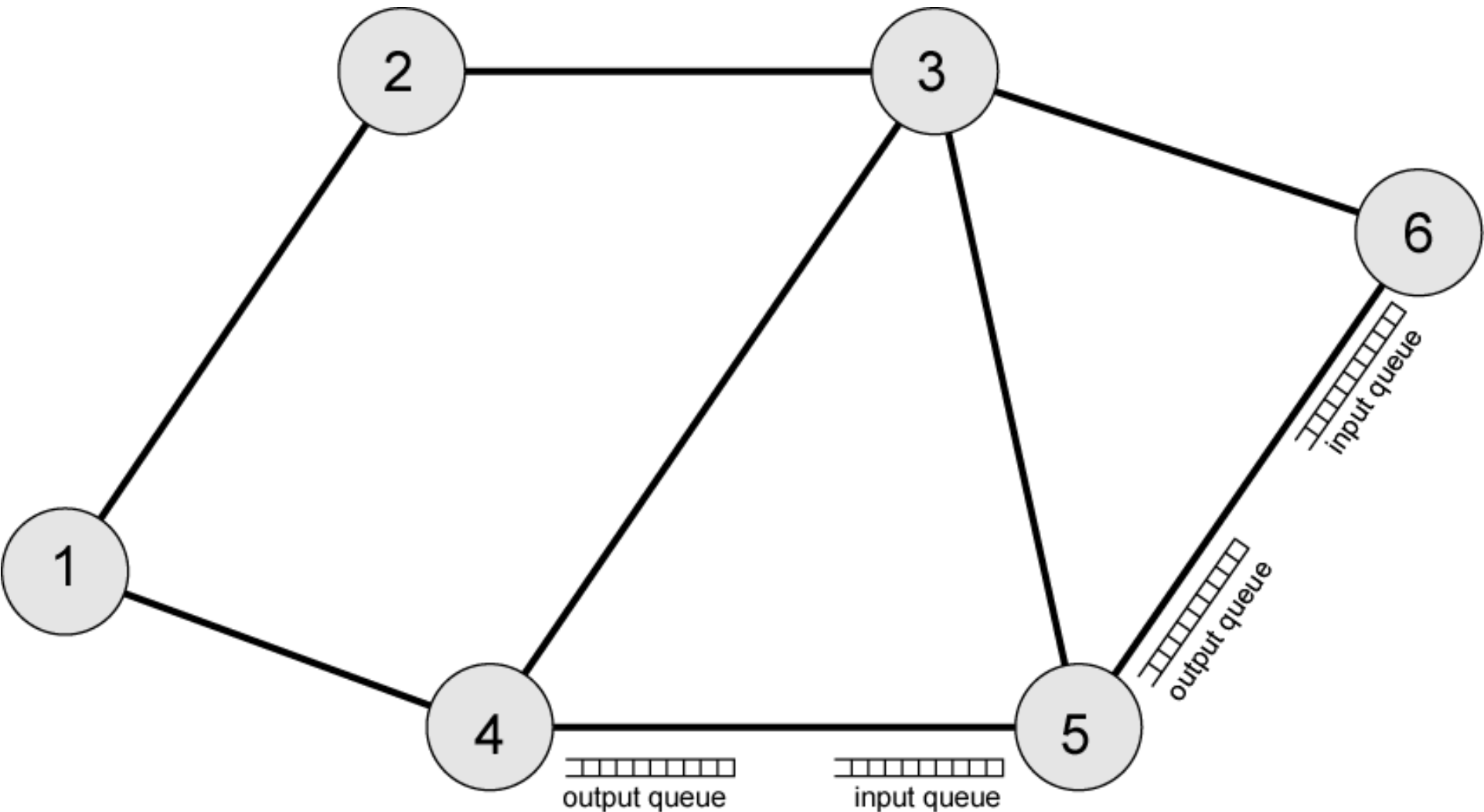
Queues at a Node



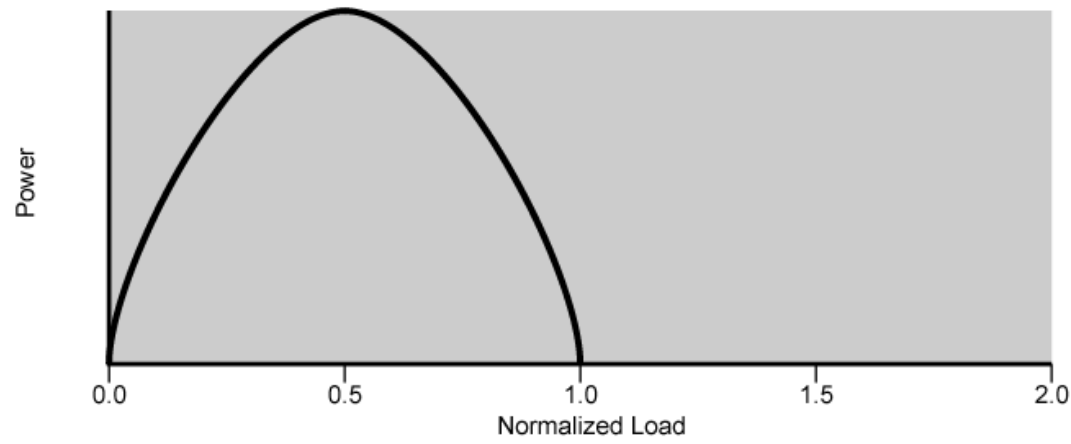
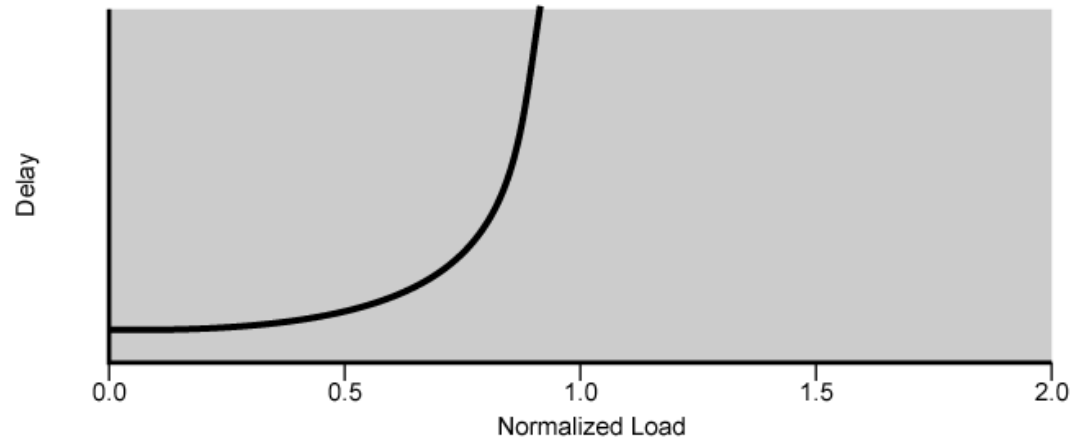
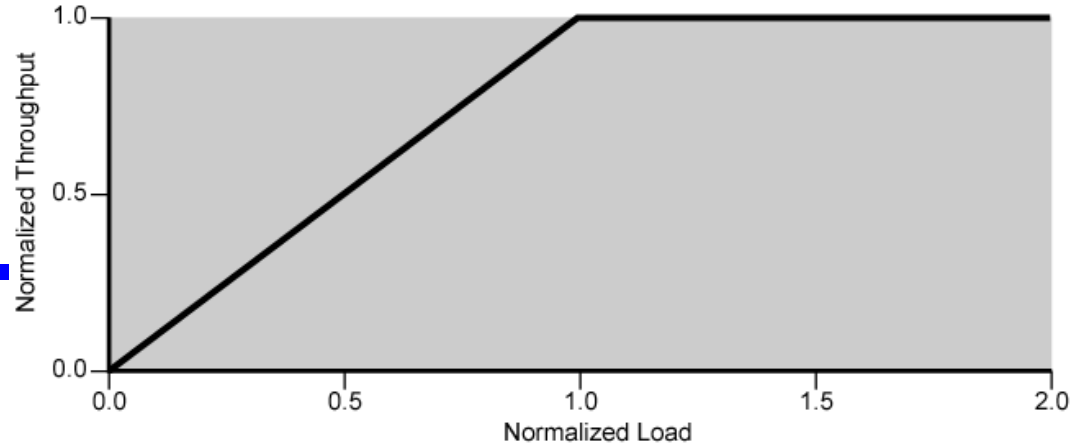
Effects of Congestion

- Packets arriving are stored at input buffers
- Routing decision made
- Packet moves to output buffer
- Packets queued for output transmitted as fast as possible
 - Statistical time division multiplexing
- If packets arrive too fast to be routed, or to be output, buffers will fill
- Can discard packets
- Can use flow control
 - Can propagate congestion through network

Interaction of Queues



Ideal Network Utilization

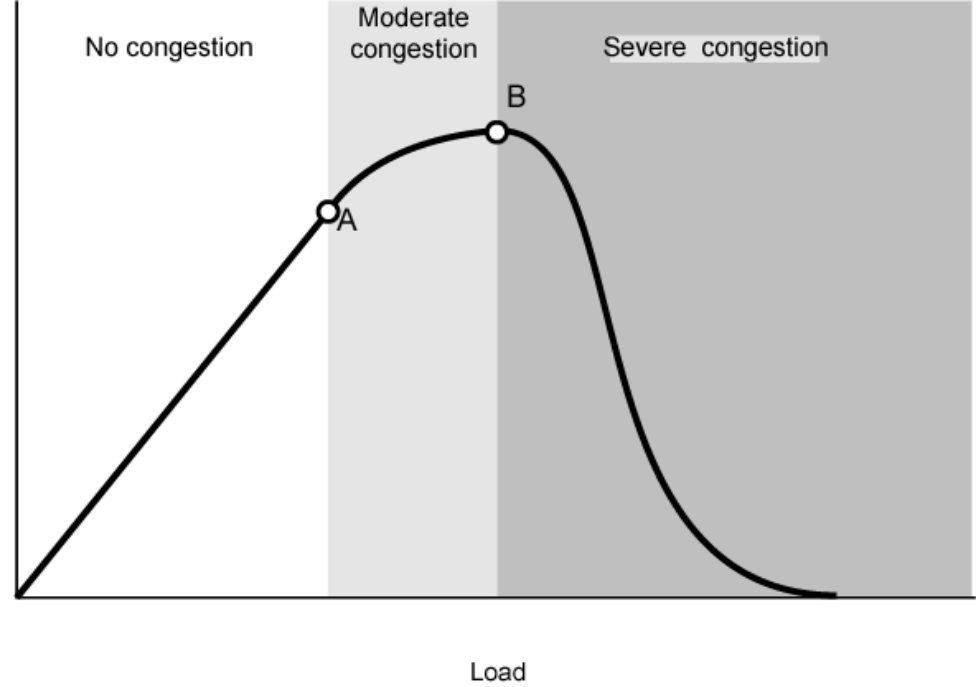


Practical Performance

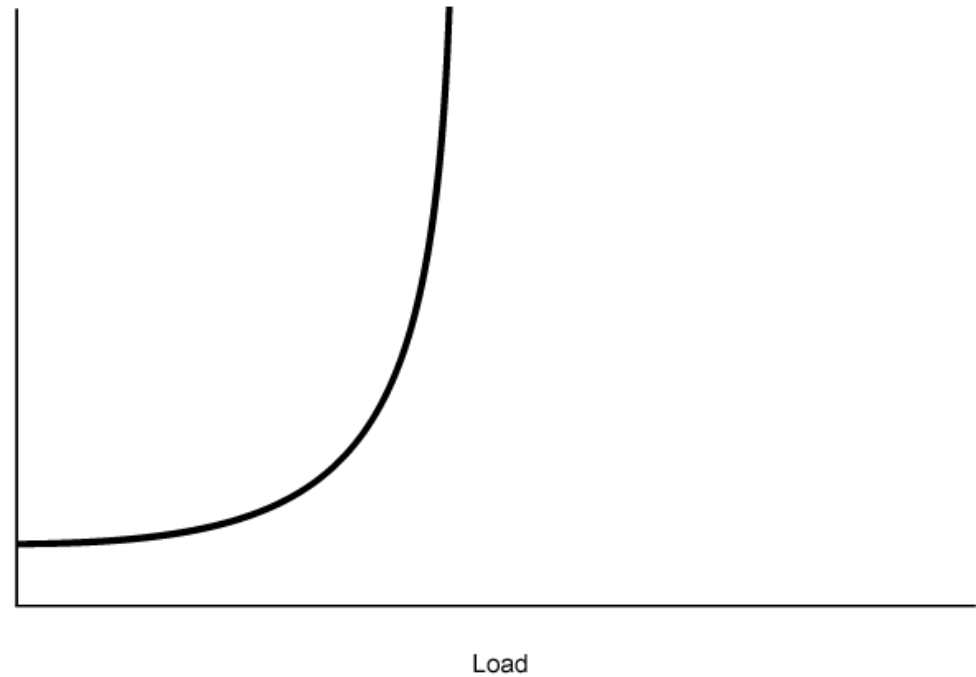
- Ideal assumes infinite buffers and no overhead
- Buffers are finite
- Overheads occur in exchanging congestion control messages

Effects of Congestion - No Control

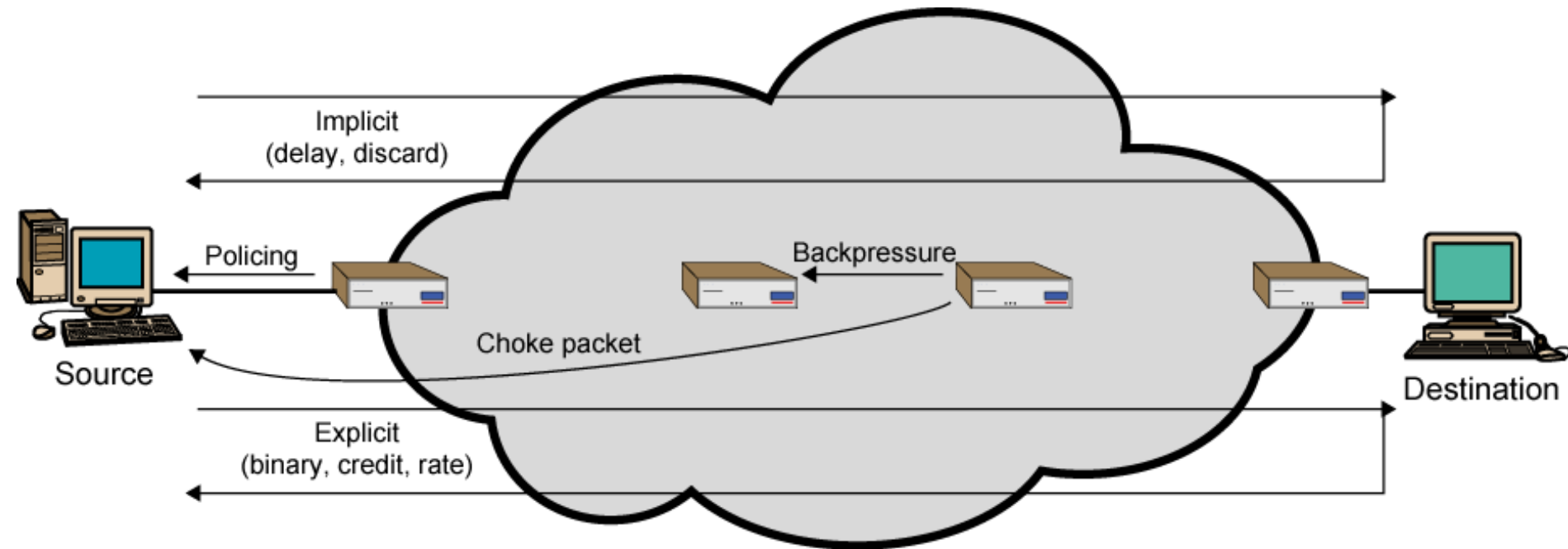
Normalized Throughput



Delay



Mechanisms for Congestion Control



Backpressure

- If node becomes congested it can slow down or halt flow of packets from other nodes
- May mean that other nodes have to apply control on incoming packet rates
- Propagates back to source
- Can restrict to logical connections generating most traffic
- Used in connection oriented that allow hop by hop congestion control (e.g. X.25)
- Not used in ATM nor frame relay
- Only recently developed for IP

Choke Packet

- Control packet
 - Generated at congested node
 - Sent to source node
 - e.g. ICMP source quench
 - From router or destination
 - Source cuts back until no more source quench message
 - Sent for every discarded packet, or anticipated
- Rather crude mechanism

Implicit Congestion Signaling

- Transmission delay may increase with congestion
- Packet may be discarded
- Source can detect these as implicit indications of congestion
- Useful on connectionless (datagram) networks
 - e.g. IP based
 - (TCP includes congestion and flow control - see chapter 17)
- Used in frame relay LAPF

Explicit Congestion Signaling

- Network alerts end systems of increasing congestion
- End systems take steps to reduce offered load
- Backwards
 - Congestion avoidance in opposite direction to packet required
- Forwards
 - Congestion avoidance in same direction as packet required

Categories of Explicit Signaling

- Binary
 - A bit set in a packet indicates congestion
- Credit based
 - Indicates how many packets source may send
 - Common for end to end flow control
- Rate based
 - Supply explicit data rate limit
 - e.g. ATM

Traffic Management

- Fairness
- Quality of service
 - May want different treatment for different connections
- Reservations
 - e.g. ATM
 - Traffic contract between user and network

Congestion Control in Packet Switched Networks

- Send control packet to some or all source nodes
 - Requires additional traffic during congestion
- Rely on routing information
 - May react too quickly
- End to end probe packets
 - Adds to overhead
- Add congestion info to packets as they cross nodes
 - Either backwards or forwards

Frame Relay

Congestion Control

- Minimize discards
- Maintain agreed QoS
- Minimize probability of one end user monopoly
- Simple to implement
 - Little overhead on network or user
- Create minimal additional traffic
- Distribute resources fairly
- Limit spread of congestion
- Operate effectively regardless of traffic flow
- Minimum impact on other systems
- Minimize variance in QoS

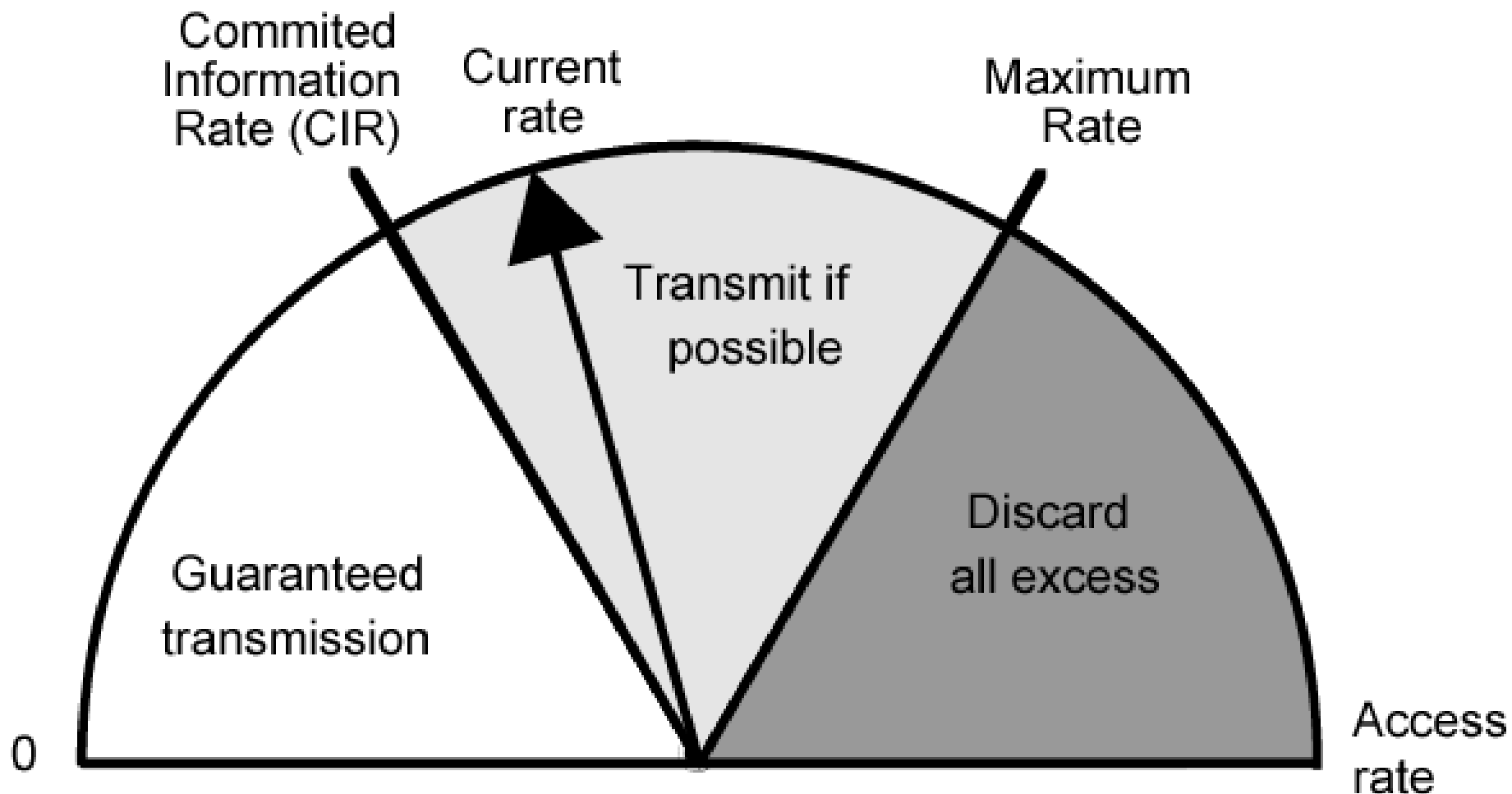
Techniques

- Discard strategy
- Congestion avoidance
- Explicit signaling
- Congestion recovery
- Implicit signaling mechanism

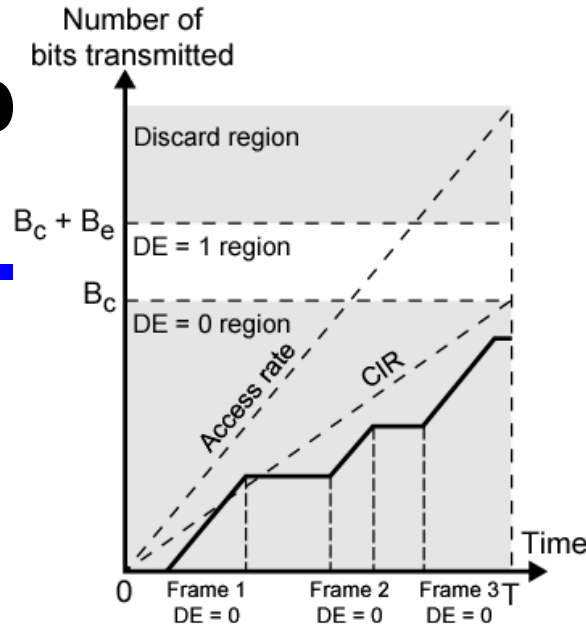
Traffic Rate Management

- Must discard frames to cope with congestion
 - Arbitrarily, no regard for source
 - No reward for restraint so end systems transmit as fast as possible
 - Committed information rate (CIR)
 - Data in excess of this liable to discard
 - Not guaranteed
 - Aggregate CIR should not exceed physical data rate
- Committed burst size
- Excess burst size

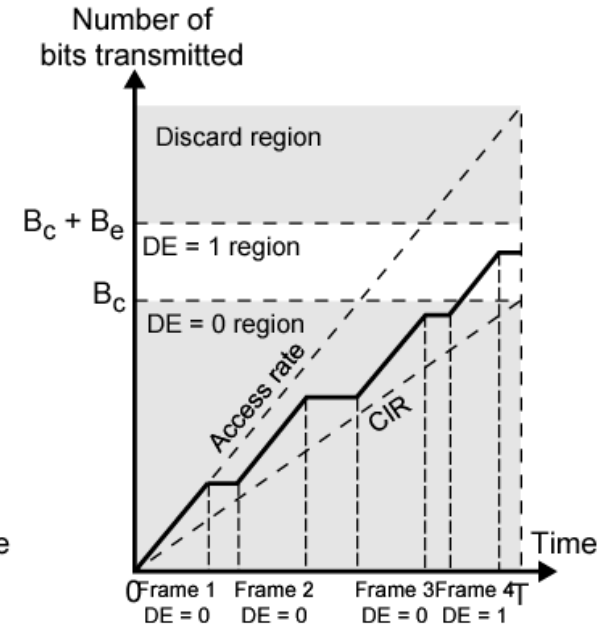
Operation of CIR



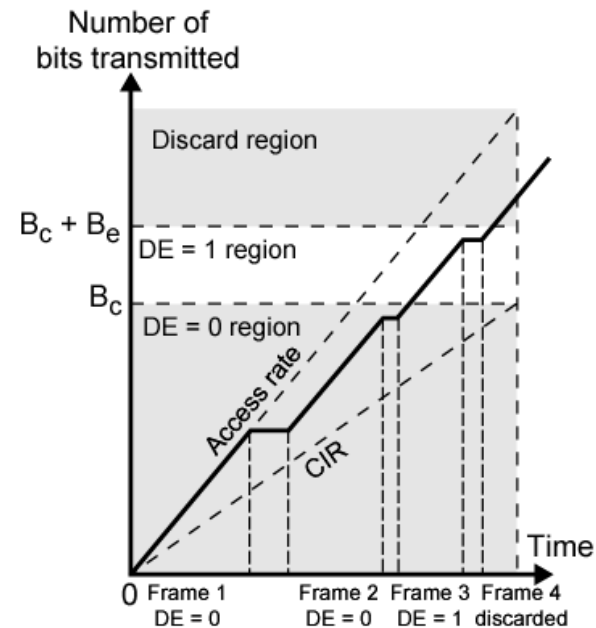
Relationship Among Congestion Parameters



(a) All frames within CIR



(b) One frame marked DE



(c) One frame marked DE; one frame discarded

Explicit Signaling

- Network alerts end systems of growing congestion
- Backward explicit congestion notification
- Forward explicit congestion notification
- Frame handler monitors its queues
- May notify some or all logical connections
- User response
 - Reduce rate

ATM Traffic Management

- High speed, small cell size, limited overhead bits
- Still evolving
- Requirements
 - Majority of traffic not amenable to flow control
 - Feedback slow due to reduced transmission time compared with propagation delay
 - Wide range of application demands
 - Different traffic patterns
 - Different network services
 - High speed switching and transmission increases volatility

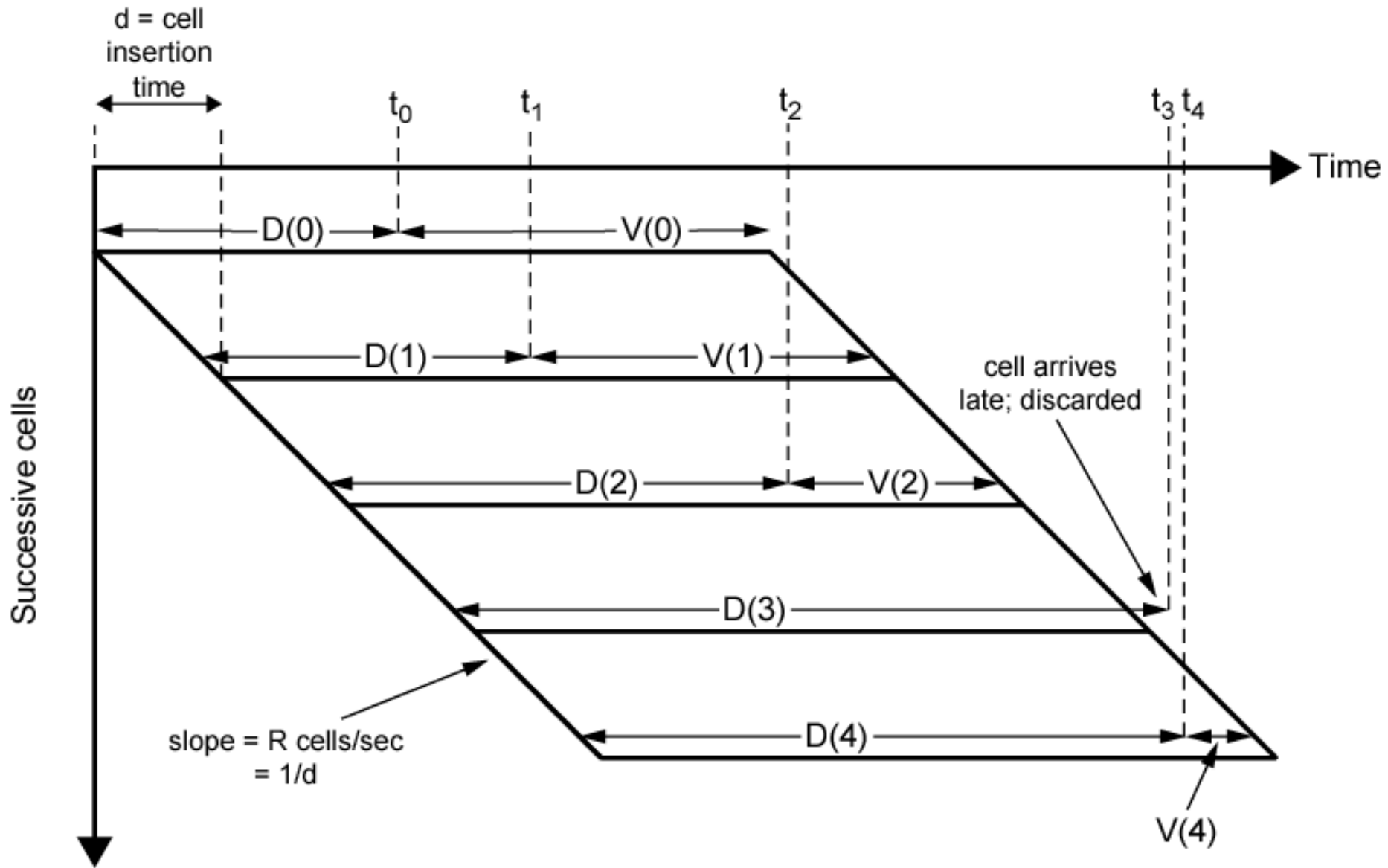
Latency/Speed Effects

- ATM 150Mbps
- $\sim 2.8 \times 10^{-6}$ seconds to insert single cell
- Time to traverse network depends on propagation delay, switching delay
- Assume propagation at two-thirds speed of light
- If source and destination on opposite sides of USA, propagation time $\sim 48 \times 10^{-3}$ seconds
- Given implicit congestion control, by the time dropped cell notification has reached source, 7.2×10^6 bits have been transmitted
- So, this is not a good strategy for ATM

Cell Delay Variation

- For ATM voice/video, data is a stream of cells
- Delay across network must be short
- Rate of delivery must be constant
- There will always be some variation in transit
- Delay cell delivery to application so that constant bit rate can be maintained to application

Time Re-assembly of CBR Cells



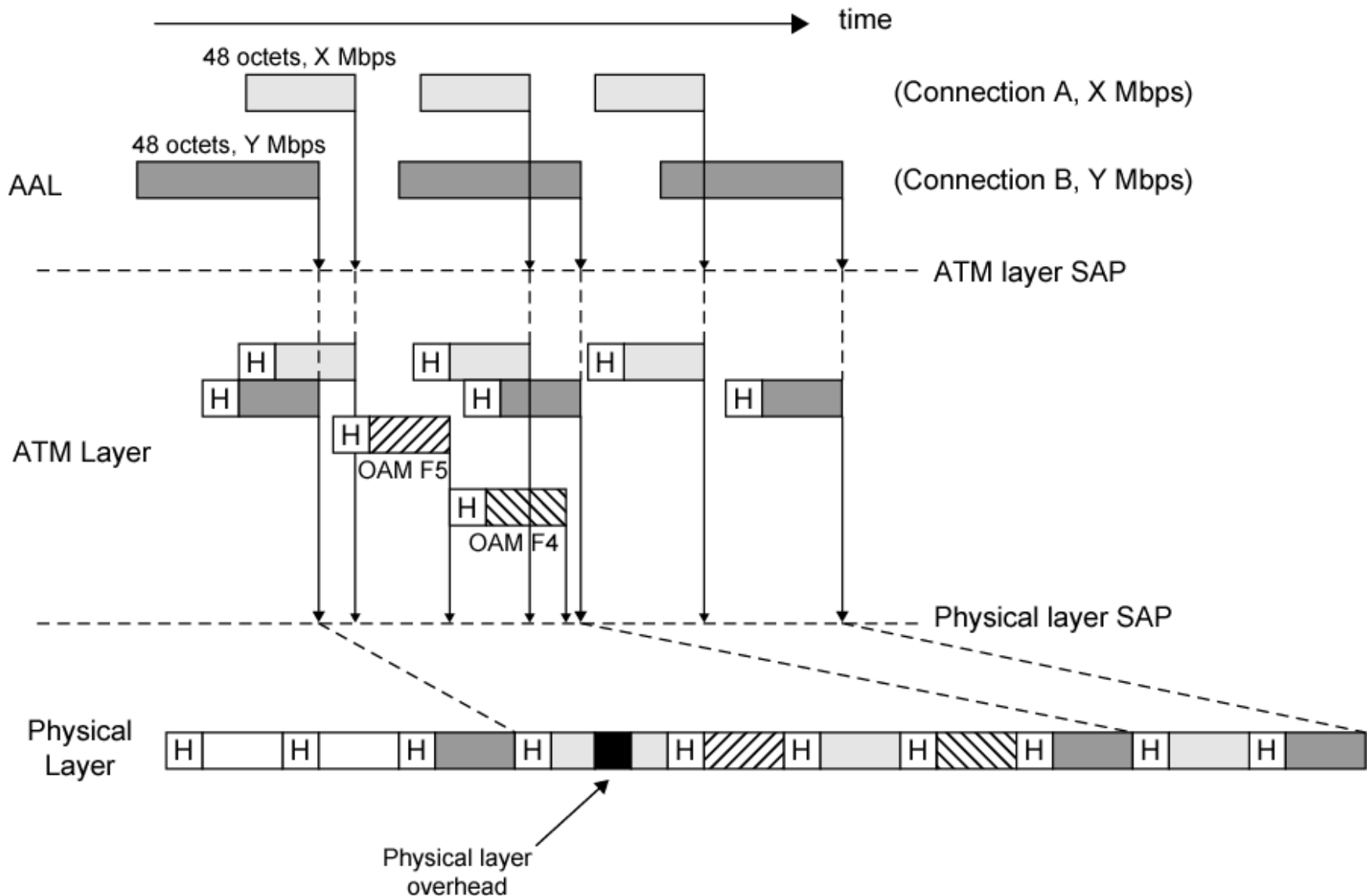
Network Contribution to Cell Delay Variation

- Packet switched networks
 - Queuing delays
 - Routing decision time
- Frame relay
 - As above but to lesser extent
- ATM
 - Less than frame relay
 - ATM protocol designed to minimize processing overheads at switches
 - ATM switches have very high throughput
 - Only noticeable delay is from congestion
 - Must not accept load that causes congestion

Cell Delay Variation At The UNI

- Application produces data at fixed rate
- Processing at three layers of ATM causes delay
 - Interleaving cells from different connections
 - Operation and maintenance cell interleaving
 - If using synchronous digital hierarchy frames, these are inserted at physical layer
 - Can not predict these delays

Origins of Cell Delay Variation



Traffic and Congestion Control Framework

- ATM layer traffic and congestion control should support QoS classes for all foreseeable network services
- Should not rely on AAL protocols that are network specific, nor higher level application specific protocols
- Should minimize network and end to end system complexity

Timings Considered

- Cell insertion time
 - Round trip propagation time
 - Connection duration
 - Long term
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- Determine whether a given new connection can be accommodated
 - Agree performance parameters with subscriber

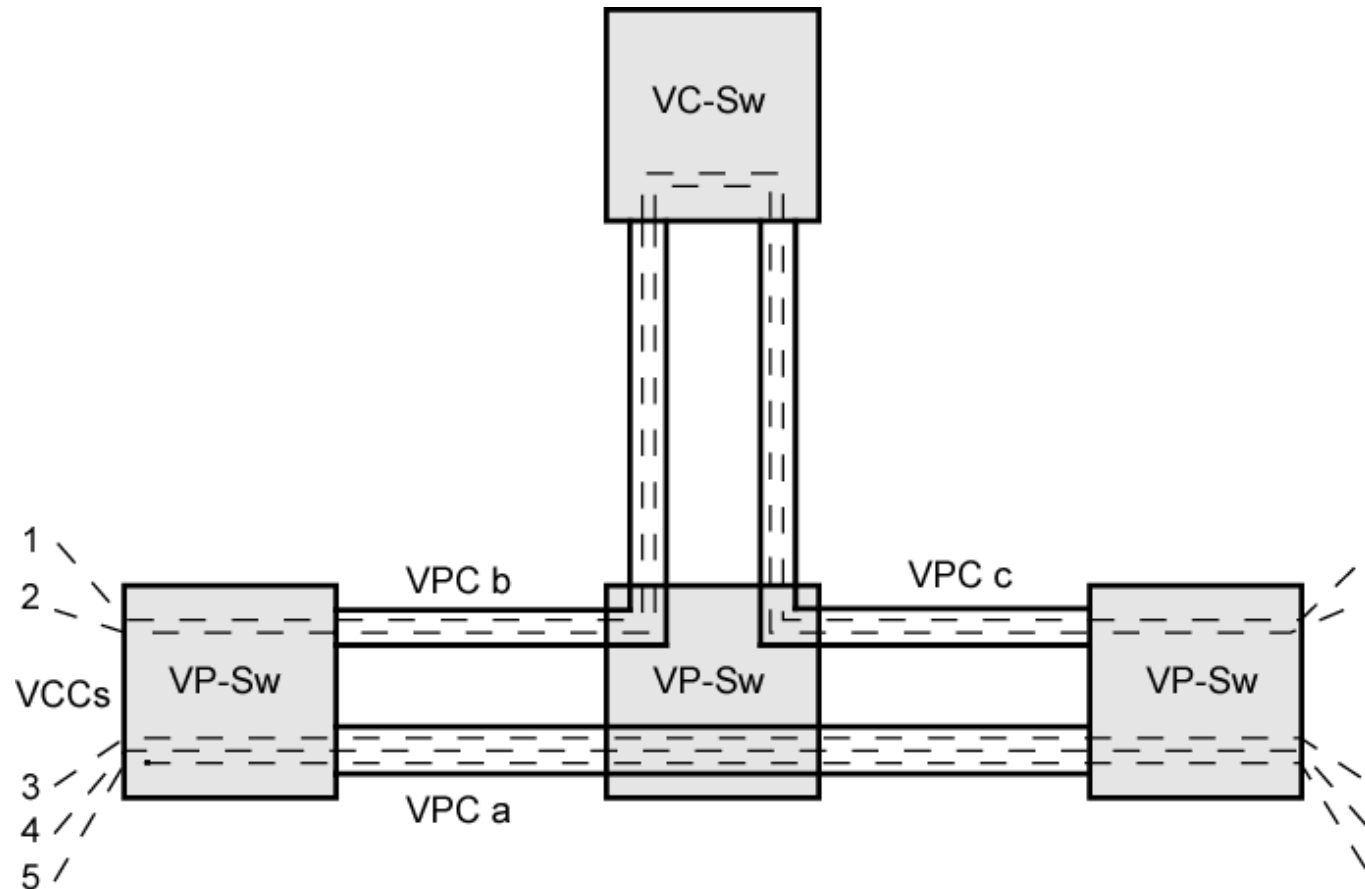
Traffic Management and Congestion Control Techniques

- Resource management using virtual paths
- Connection admission control
- Usage parameter control
- Selective cell discard
- Traffic shaping

Resource Management Using Virtual Paths

- Separate traffic flow according to service characteristics
- User to user application
- User to network application
- Network to network application
- Concern with:
 - Cell loss ratio
 - Cell transfer delay
 - Cell delay variation

Configuration of VCCs and VPCs



- VPC = Virtual path connection
- VCC = Virtual channel connection
- VP-Sw = Virtual path switching function
- VC-Sw = Virtual channel switching function

Allocating VCCs within VPC

- All VCCs within VPC should experience similar network performance
- Options for allocation:
 - Aggregate peak demand
 - Statistical multiplexing

Connection Admission Control

- First line of defense
- User specifies traffic characteristics for new connection (VCC or VPC) by selecting a QoS
- Network accepts connection only if it can meet the demand
- Traffic contract
 - Peak cell rate
 - Cell delay variation
 - Sustainable cell rate
 - Burst tolerance

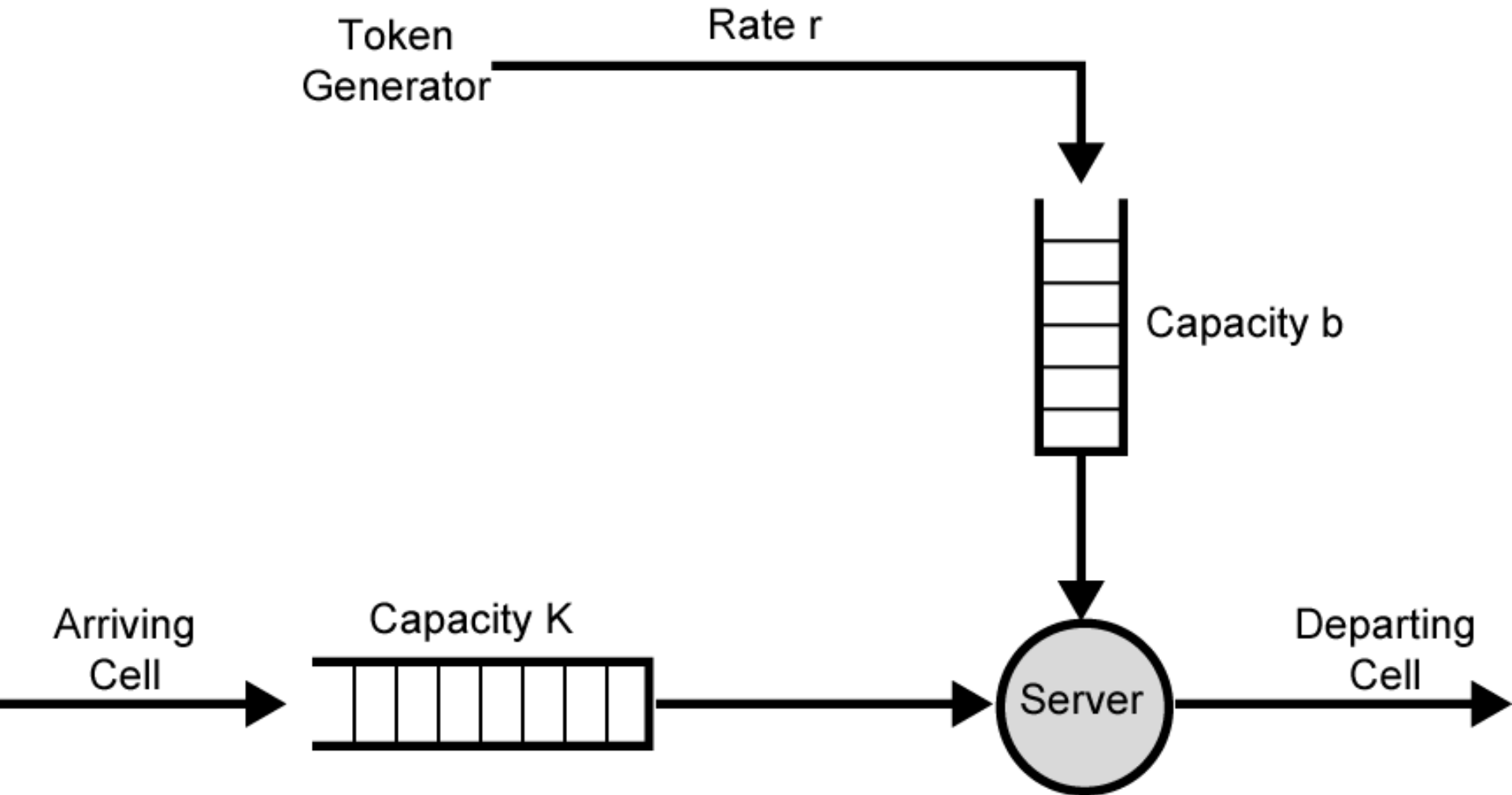
Usage Parameter Control

- Monitor connection to ensure traffic conforms to contract
- Protection of network resources from overload by one connection
- Done on VCC and VPC
- Peak cell rate and cell delay variation
- Sustainable cell rate and burst tolerance
- Discard cells that do not conform to traffic contract
- Called traffic policing

Traffic Shaping

- Smooth out traffic flow and reduce cell clumping
- Token bucket

Token Bucket for Traffic Shaping



GFR Traffic Management

- Guaranteed frame rate is as simple as UBR from end system viewpoint
- Places modest requirements on ATM network elements
- End system does no policing or shaping of traffic
- May transmit at line rate of ATM adaptor
- No guarantee of delivery
 - Higher layer (e.g. TCP) must do congestion control
- User can reserve capacity for each VC
 - Assures application may transmit at minimum rate without losses
 - If no congestion, higher rates maybe used

Frame Recognition

- GFR recognizes frames as well as cells
- When congested, network discards whole frame rather than individual cells
- All cells of a frame have same CLP bit setting
- CLP=1 AAL5 frames are lower priority
 - Best efforts
- CLP=0 frames minimum guaranteed capacity

GFR Contract Parameters

- Peak cell rate (PCR)
- Minimum cell rate (MCR)
- Maximum burst size (MBS)
- Maximum frame size (MFS)
- Cell delay variation tolerance (CDVT)

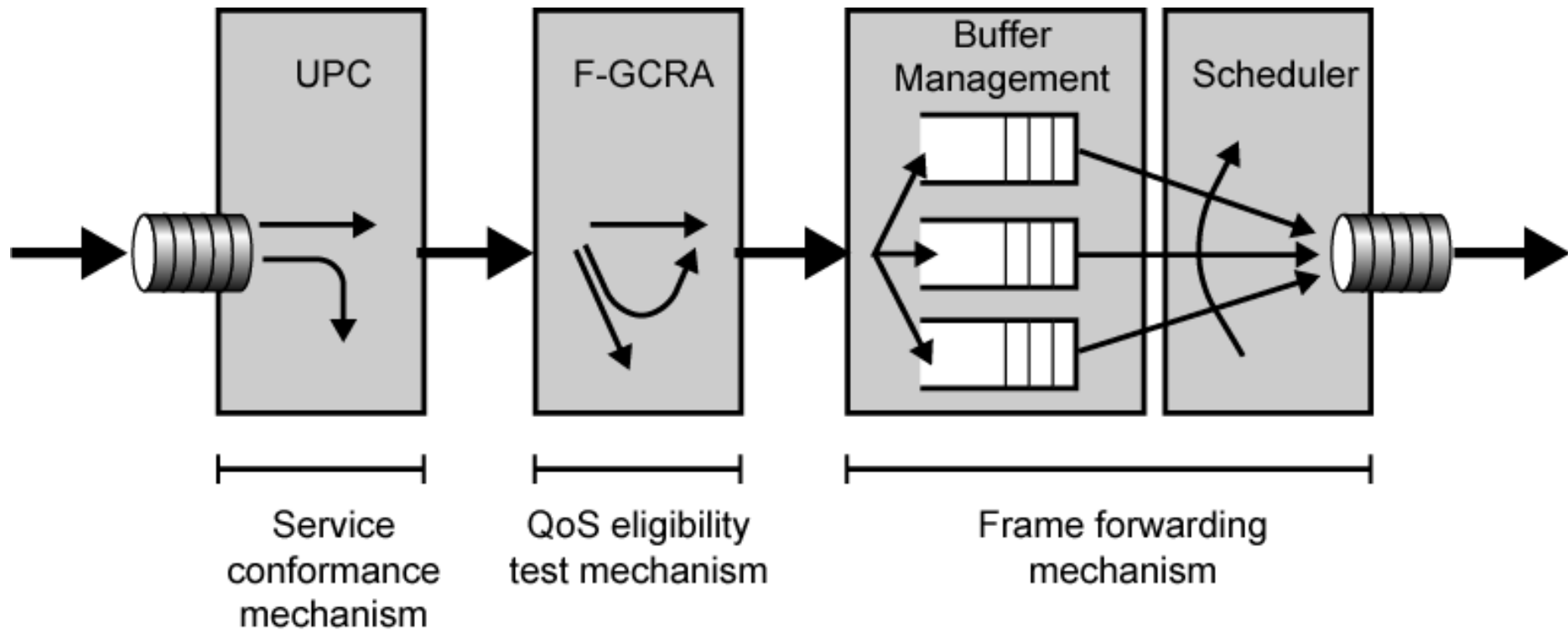
Mechanisms for Supporting Rate Guarantees (1)

- Tagging and policing
 - Discriminate between frames that conform to contract and those that don't
 - Set CLP=1 on all cells in frame if not
 - Gives lower priority
 - Maybe done by network or source
 - Network may discard CLP=1 cells
 - Policing
- Buffer management
 - Treatment of buffered cells
 - Congestion indicated by high buffer occupancy
 - Discard tagged cells
 - Including ones already in buffer to make room
 - To be fair, per VC buffering
 - Cell discard based on queue-specific thresholds

Mechanisms for Supporting Rate Guarantees (2)

- Scheduling
 - Give preferential treatment to untagged cells
 - Separate queues for each VC
 - Make per-VC scheduling decisions
 - Enables control of outgoing rate of VCs
 - VCs get fair capacity allocation
 - Still meet contract

Components of GFR System



Conformance Definition

- UPC
 - Monitors each active VC
 - Ensure traffic conforms to contract
 - Tag or discard nonconforming cells
 - Frame conforms if all cells conform
 - Cell conforms if:
 - Rate of cells within contract
 - All cells in frame have same CLP
 - Frame satisfies MFS parameter (check for last cell in frame or cell count < MFS)

QoS Eligibility Test

- Two stage filtering process
 - Frame tested for conformance to contract
 - If not, may discard
 - If not discarded, tag
 - Sets upper bound
 - Penalize cells above upper bound
 - Implementations expected to attempt delivery of tagged cells
 - Determine frames eligible for QoS guarantees
 - Under GFR contract for VC
 - Lower bound on traffic
 - Frames making up traffic flow below threshold are eligible

GFR VC Frame Categories

- Nonconforming frame
 - Cells of this frame will be tagged or discarded
- Conforming but ineligible frames
 - Cells will receive a best-effort service
- Conforming and eligible frames
 - Cells will receive a guarantee of delivery

Required Reading

- Stallings chapter 13